Enzymatic Strength Development in OCC

Rosa M. Covarrubias
Product Development Manager
Buckman Laboratories International
1256 N. McLean Blvd.
Memphis, TN 38108

Introduction:

The use of recycled fibers in the paper industry has been an economic and environmental requirement over the last 20 years. The increased recycling rate of fibers has resulted in a decrease in pulp strength and on the bonding strength between fibers.

Over the last 25 years, the use of recovered fiber to increase mill capacity has increased sharply. U.S. paper recovery increased from 36.8 million short tons/year in 1995 to about 68 million short tons/year currently (nearly 50% recovery).

Some underlying trends are creating new technical challenges for many paper recyclers and users. World fiber demand will continue to increase, as will the use of recovered fiber. To meet this demand, mills must develop grades from lower quality mixed paper streams. Rising package/container exports from new Asian paper mills will increase the quantity of inferior quality old corrugated containers (OCC) in U.S. recovered paper streams.

To sustain and improve our industry's position, we must improve profitability through dramatic innovations that reduce manufacturing costs and improve the quality of fiber delivered to the paper machine. Beating and refining are mechanical processes that can enhance fibrillation and internal fiber bonding. There is a limit to the effectiveness of traditional mechanical approaches. Properly applied enzymes can enhance the refining process, increase fiber strength, reduce refining time, and increase inter-fiber bonding through more effective fibrillation.

Refining is a mechanical process that involves the crushing of the wood fibers between rotating surfaces. This causes the fibers, which are hollow, to collapse and flatten. Refining also produces many smaller fibers to extend from the surface of the wood fiber. Since the strength of a sheet of paper derives from hydrogen bonding at the fiber surface, this flattening of the fiber and fibrillation of its surface gives an exponential increase in the amount of surface where bonding can occur, and is essential in forming the sheet of paper.

Refining requires significant energy input, as well as capital investment. Reducing the need for mechanical refining could provide numerous benefits. These benefits are listed in Table 1.
### Table 1 - EFFECTS FROM ENZYME RESULTING BENEFITS

<table>
<thead>
<tr>
<th>EFFECTS FROM ENZYME</th>
<th>RESULTING BENEFITS</th>
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<tbody>
<tr>
<td>Increases strength of paper sheet by improving inter-fiber bonding</td>
<td>Improved quality</td>
</tr>
<tr>
<td></td>
<td>Increased use of recycled fiber</td>
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<td></td>
<td>Elimination of chemicals used for sheet strength</td>
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<td></td>
<td>Improved softness in tissue</td>
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<td></td>
<td>Allows production of paper requiring very intense refining</td>
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<td>Increases strength, allowing reduction in sheet weight</td>
<td>Reduced use of wood pulp</td>
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<tr>
<td>Can reduce sheet porosity</td>
<td>Reduced pressure on natural wood resources</td>
</tr>
<tr>
<td>Reduces energy required for refining fiber</td>
<td>Reduced use of coating chemicals</td>
</tr>
<tr>
<td>Improves other paper qualities</td>
<td>Reduced need for energy production</td>
</tr>
<tr>
<td></td>
<td>Economic benefit to mill</td>
</tr>
<tr>
<td></td>
<td>May eliminate need for investment in new refiners</td>
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<tr>
<td></td>
<td>Improved printability, porosity, formation, etc.</td>
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### Enzymes in the paper industry:

The use of environment friendly processes is becoming more popular in the pulp and paper industry and therefore biotechnological processes are coming to the forefront of research. Biotechnology is defined as the use of biological organisms/systems and processes for practical or commercial purposes. In this broad sense, biotechnology encompasses a diverse array of activities including fermentation, immobilized cell and enzyme technology.

The attractiveness of biotechnology lies in its potential to increase specificity in reactions, to provide more environmentally friendly processes, to save energy, and by virtue of the foregoing, to decrease cost. The raw material in forest-based industries is wood and its components. Thus, possibilities for employing biotechnology in these industries are numerous, as one of nature’s most important biological processes is the degradation of lignocelluloses materials.

Enzymes are biological catalysts that facilitate a great variety of reactions. Advantages of enzymes include their high selectivity, reaction speed and efficiency. The number of application of enzymes in pulp and paper manufacture has grown steadily and there are several enzymes that are commercially available for different uses. These enzymes include xylanases for bleach reduction and brightness increase, lipases for pitch control, esterases for stickies control, amylases for starch modification, proteases for microbial and biofilm control, and more recently cellulases and hemicellulases for fiber modification.

### Enzymatic Fiber Modification

Wood fibers are mainly composed of cellulose and hemicellulose microfibrils encrusted in lignin-carbohydrate matrices. They are multilayered structures that can have internal delamination and external fibrillation after chemical and/or mechanical processing.
Wood pulp can be treated with enzymes, and some of the cellulose in the fiber is hydrolyzed. This biochemical treatment reduces the amount of mechanical treatment needed to reach the desired fiber properties. Less mechanical action and less energy are required. Since refining requires significant energy input, as well as capital investment for equipment, facilitating the refining process could provide numerous benefits, including stronger paper, more use of recycled paper, elimination of other chemical additives, reduced energy usage, and improvement in various tissue properties.

Mill applications prove the benefit of this technology, with a variety of advantages seen: increased paper sheet strength, which in turn allows manufacture of paper with less fiber, giving a saving in raw materials (and natural resources) used. Also, with this increased strength more recycled fiber can be used. Additionally less petroleum-based chemicals are required to give strength to the sheet. In some cases enzymes can be used in place of purchasing additional equipment for refining. In some situations the product directly contacts food and, because of the nontoxic nature of an enzyme, its use is preferred. Enzymes are a very attractive green chemistry. They are produced from renewable resources and are completely recyclable.

Laboratory Studies

Each enzyme in nature is very specific as to what substrate it will act upon. Even within the cellulase family of enzymes, different enzymes react differently with different types of fiber. Cellulases can be categorized into two broad classes, exocellulases and endocellulases. Exocellulases cleave cellulose polymers from the terminal points, while endocellulases randomly cleave bonds along the cellulose chain. Depending upon many factors, including wood species, pulping processes and others, various enzymes will have varying degrees of activity on fibers. So, due to the differences in enzymes and fiber types, enzyme selection must be carried out carefully.

In order to select the appropriate enzyme for a particular application or fiber type, several enzymes are chosen for each test. The pulp suspensions are treated with these enzymes, and allowed to react under appropriate temperature conditions for one hour. At this time, the enzyme reaction is stopped with bleach.

At this stage, fiber is then refined in a PFI mill laboratory scale refiner. Normally, several levels of refining are chosen, so that a refiner curve can eventually be developed. Freeness levels are measured and recorded, and handsheets are then made with the remaining fiber. Based upon the typical dry end test parameters of the subject paper mill, dry end testing is then performed. Tensile, including standard and short-span, as well as tear, burst, compression, and other tests can be performed in order to determine the enzyme’s affect on the fiber.

An example of the specificity of the enzymes can be seen below. In Figures 1-3, OCC furnish was treated with four different enzyme solutions.
Results of the CSF testing are given in Figure 1. CSF for the samples treated with enzymes A, B, & C were close to the control sample, however, the enzyme D treated sample had a 14% reduction in CSF. This indicates that the action of the enzyme on the fiber has reduced the refining energy requirement. The Tear strength comparison (Figure 2) indicated no difference with enzymes A-C. Treatment with enzyme D resulted in a 12% Tear decrease. This is in agreement with the reduction in CSF associated with this enzyme. There was an 11% increase in ring crush associated with enzyme D treatment (Figure 3).

Figure 1: CSF Results
Figure 2: Tear Results

*Tear Vs Enzyme Treatment*

Control Enzyme A Enzyme B Enzyme C Enzyme D

Tear Index

Figure 3: Ring Crush Results.

*Ring Crush Vs Enzyme Treatment*

Control Enzyme A Enzyme B Enzyme C Enzyme D

Ring Crush
Mill Application:

While the laboratory testing above is exciting by itself, actual application in a paper mill is the only way to determine the validity of the theory and laboratory tests. We have now an ongoing application in OCC and several evaluations underway.

This North American mill producing Kraft paper currently uses virgin fiber to meet specs. The Fourdrinier machine runs at 1200 fpm producing 100-140 tpd of 40-100 pound grades. The mill has been struggling to meet specs using 100% OCC due to the quality of the recycle they are getting, thus having to use virgin and/or dry strength additives to meet quality.

BLX 13090 was the product selected in the lab. During the initial evaluation on a 40# Kraft we achieved a significant increase in Mullen (32%) and tear was decreased by around 1.8% in both MD and CD directions. To compensate for decreasing tear, the refiner was turned down by 20% and tear came back into specification. Drainage was increased and the machine was able to speed up by 50 fpm.

A second evaluation was run on 84# grade and again we saw similar results. In addition the mill got a very positive feedback from the converter regarding the first evaluation production.

Mill is running full time the enzyme without having to use any virgin fiber and achieving better quality than before.

Conclusions

There are a number of steps involved in running an effective enzymatic fiber modification program. First, determination of the desired end result is critical. By choosing the final result first, the second step, laboratory work, can be applied more effectively. Do you want higher tensile strength, reduced energy consumption, a higher degree of softness in tissue? Which aspect of fiber modification will best fit your marketing plan?

The second step in determining the appropriate lab work is in understanding the papermaking process. Are the fiber streams refined separately, together or not at all? What temperature or pH limitations are there that might affect enzyme performance? All of these will determine how the lab testing is performed.

After product determination, the next step is trial planning. Keeping the end result in mind, the trial plan should include the variables that will be used to take advantage of the fiber modification. These variables can include anything that a mill would typically change in order to take advantage of this easier to refine fiber source.

While there will be some time in development of all of this information and learning how to run these programs, the end result for the papermaker is going to be substantial.
Energy costs are escalating, small changes in paper quality can affect the ability to be in a particular market, and having the flexibility to rationalize fiber sources, depending upon current fiber pricing will have significant financial impact on the papermill’s bottom line.